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Study on backwash wastewater from rapid sand-filter by monolith ceramic membrane☆

Li Weiying [a,c,*], Akira Yuasa [b], Dong Bingzhi [c], Deng Huiping [c], Gao Naiyun [a,c]

[a] State Key Laboratory of Pollution Control and Resource Reuse, Tongji University, Shanghai: 200092, China
[b] River Basin Research Center, Gifu University,1-1,Yanagido, Gifu 501-1193, Japan
[c] Key Laboratory of Yangtze Aquatic Environment, Ministry of Education College of Environmental Science and Engineering, Tongji University, Shanghai: 200092, China

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ABSTRACT

To verify the feasibility of membrane micro-filtration process to treat the sand-filter backwash wastewater and the sediment sludge withdrawn from the coagulation–flocculation–settling tank, a multi-lumen monolith ceramic membrane module was applied in a test pilot plant. The ceramic membrane filtration was operated very stably at the filtration flux of 4 m/day when the sand-filter backwash wastewater was fed. The membrane filtration was also operated very stably at the flux of 2 m/day when the mixture of the sand-filter backwash wastewater and the sediment sludge was fed. The level of these substances in the membrane filtrate was very low and met drinking water standards.

1. Introduction

During most water treatment processes, spent filter backwash water is generated. A continuously increasing world population as well as higher quality standards and expenses for drinking water lead to numerous efforts to apply water reuse systems [1], which make it more important to improve the productivity of drinking water treatment. Membrane technology offers a wide range of possibilities to set up and operate water reuse plants with improved product water quality, lower treatment costs and increased overall efficiencies. The membrane technology has been considered as a substitute for conventional drinking water treatment for effective retention of particulates, bacteria and some viruses [2–4]. Backwashing process is normally used in conventional drinking water treatment and membrane technology to remove fouling on filtration materials and membranes [5,6].

Backwash wastewater from rapid sand-filter is usually returned to the raw water receiving or feeding tank and mixed with the raw water in many drinking water treatment plants (DWTPs) in Japan. Although the reuse of the backwash wastewater is important to save the water resource, it brings about the recycling of once removed particulates including pathogens in treatment processes. The accumulation of the protozoan parasites such as *Cryptosporidium parvum* and *Giardia lamblia* is undesirable because it may induce the serious pollution and infection in case of unforeseen failure or malfunction of sedimentation and rapid sand filtration processes.

Membrane filtration of the backwash wastewater is one of the choices to avoid such a serious consequence[7,8]. Sediment sludge withdrawn from settling tank after flocculation is usually treated in a gravity thickening tank and the thickened sludge is sent to a further dewatering process. Membrane filtration is an alternative of the thickening and dewatering process of the sediment sludge in a rapid sand filtration system [9–11].

The purpose of this study is to verify the feasibility of membrane micro-filtration process to treat the sand-filter backwash wastewater and the sediment sludge withdrawn from the coagulation–flocculation–settling tank, a multi-lumen monolith ceramic membrane module was applied in a test pilot plant.

2. Methods

2.1. Data resources

The experiments were carried out in the test pilot plant installed at the Kasugai DWTP of the Water Works, City of Nagoya from June to December, 2003. The raw water in this DWTP was taken from the Kiso River and the integrated coagulation–flocculation–settling tanks (Pulsators and Accelerators) were in service with the dose of polyaluminum chloride (PACl) or aluminum sulfate as coagulant.

2.2. Membrane module

The specification and the appearance of the ceramic membrane element were given in Table 1 and Fig. 1, respectively.

The raw water was sent pressurized by the feeding pump to the membrane module containing seven ceramic membrane elements at

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* Corresponding author. Tel.: +86 21 28342163.
E-mail address: lwsds@163.com (L. Weiying).

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Table 1
Specification of ceramic membrane.

Pore size	0.1 μm
Monolith	Diameter: 30 mm Length: 1000 mm
Lumens	Number of lumens: 61 Diameter: 2.5 mm
Surface area	0.48 m^2
Initial specific flux	30 m/day 100 kPa, 25 °C

Table 2
Experimental conditions.

	Run 1	Run 2	Run 3	Run 4
Dose of coagulant, PACl	0	1 mg/L[a]	0	0
Dose of Cl_2 to membrane backwashing water	0	0	0	2–5 mg/L
Feed wastewater	Sand-filter backwash wastewater		Mixture of sand-filter backwash wastewater and sediment sludge	
Filtration flux ($m^3/m^2/d$)	4.0		2.0	
Allowed increase of P_{tm} in a filtration cycle[b]	30 kPa		30 kPa	

[a] As Al_2O_3.
[b] P_{tm}: trans-membrane pressure.

a controlled flow rate and was filtrated from the inside channel of lumens to the outside of the element. The module was set vertically and the raw water was fed from the bottom side of the module. The filtration was operated in a dead-end mode and the trans-membrane pressure increases with time in the filtration phase. The backwash was applied when the breadth of upsurge of the trans-membrane pressure in each filtration cycle reached 30 kPa. The backwash water was sent pressurized from the filtrate stock tank to the exterior surface of the monolith element and the compressed air was blown into the lumens from the upper side of the module. In some cases, sodium hypochlorite (NaClO) solution was injected to the backwash water to prevent the membrane fouling.

2.3. Feed wastewater

The sand-filter backwash wastewater was continuously taken from the wastewater storage tank in the Kasugai DWTP. The sediment sludge withdrawn from the integrated coagulation–flocculation–settling tank was also continuously supplied in this DWTP. The mixture of the sand-filter backwash wastewater and the sediment sludge was used as the feed wastewater in some runs. The volume of the sand-filter backwash wastewater is four times that of the sediment sludge in the mixed wastewater according to the actual ratio in this DWTP.

2.4. Experimental conditions

The experimental conditions are given in Table 2. The sand-filter backwash wastewater was used as the feed wastewater in runs 1 and 2. The filtration flux was controlled at 4.0 m/day following the result of the previous test runs. PACl was dosed at 1 mg/L as Al_2O_3 in run 2, while the coagulant was not dosed in run 1. The quality of the feed wastewater in runs 1 and 2 is shown in Table 3.

The mixture of the sand-filter backwash wastewater and the sediment sludge was used as the feed wastewater in runs 3 and 4. The filtration flux was controlled at 2.0 m/day following the results of previous test runs. The coagulant was not dosed in both runs 3 and 4. NaClO solution was injected to the backwash water in run 4 so as to give the Cl_2 concentration between 2 and 5 mg/L. The quality of the feed wastewater in runs 3 and 4 is shown in Table 3.

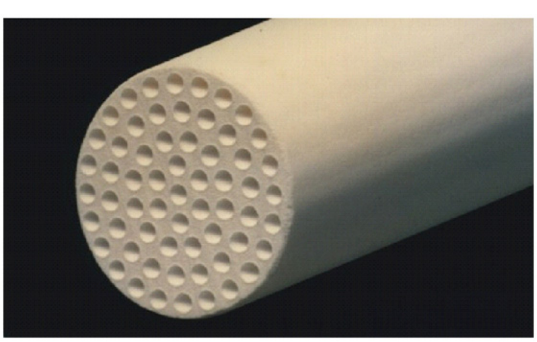

Fig. 1. Multi-lumen monolith ceramics.

3. Results and discussions

3.1. Sand-filter Backwash Wastewater

The results of runs 1 and 2 are given in Fig. 2 and Table 3. The feed wastewater contains suspended solids in the range between 30 and 60 mg/L as Standard Kaolin Turbidity Unit (TU) and organics in the range between 15 and 21 mg/L as $KMnO_4$ consumption as shown in Table 3. The membrane filtration removed the suspended particulates to the undetectable level (less than 0.1 TU). The level of $KMnO_4$ consumption decreased to 3 mg/L on average. Though the concentration of metals such as iron, manganese and aluminum is rather high in the feed water, the level in the membrane filtrate is very low and meets the drinking water standards as shown in Table 3.

The membrane filtration was operated very stably in runs 1 and 2 as shown in Fig. 2. The measured trans-membrane pressure was corrected to give the value at 25 °C to compensate the temperature variation and thus corrected trans-membrane pressure was shown in Fig. 2. The time interval of the membrane backwashing varied in the range between 120 and 180 min for both runs 1 and 2. The average daily increase of the corrected trans-membrane pressure is 0.67 kPa and 0.77 kPa for runs 1 and 2, respectively. Thus, the increase of the trans-membrane pressure is very moderate for both runs and the coagulant dose is not necessary for the membrane filtration of the sand-filter backwash wastewater. It is estimated that the chemical washing should be practiced every 3 or 4 months in order to keep the actual trans-membrane pressure less than 100 kPa.

3.2. Mixture of sand-filter backwash wastewater and sediment sludge

The results of runs 3 and 4 are given in Fig. 3 and Table 4. The feed wastewater contains suspended solids in the range between 140 and

Table 3
Experimental conditions.

	Run 1	Run 2	Run 3	Run 4
Dose of coagulant, PACl	0	1 mg/L[a]	0	0
Dose of Cl_2 to membrane backwashing water	0	0	0	2–5 mg/L
Feed wastewater	Sand-filter backwash wastewater		Mixture of sand-filter backwash wastewater and sediment sludge	
Filtration flux ($m^3/m^2/d$)	4.0		2.0	
Allowed increase of P_{tm} in a filtration cycle[b]	30 kPa		30 kPa	

[a] As Al_2O_3.
[b] P_{tm}: trans-membrane pressure.

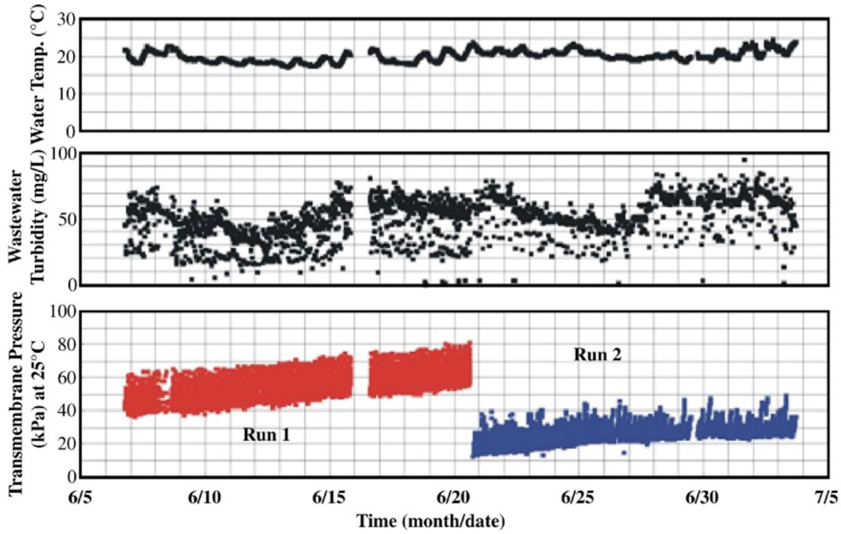

Fig. 2. Change of wastewater turbidity, temperature and corrected trans-membrane pressure.

680 mg/L as Standard Kaolin Turbidity Unit (TU) and organics in the range between 100 and 300 mg/L as $KMnO_4$ consumption. The membrane filtration removed the suspended particulates to the undetectable level (less than 0.1 TU). Particles larger than 1 µm were not detected by a particle counter and neither general germs nor *E. coli* was found in the membrane filtrate for both runs 3 and 4. The level of $KMnO_4$ consumption decreased to 4 mg/L on average. Though the concentration of metals such as iron, manganese and aluminum is very high in the feed water, the level in the membrane filtrate is very low and meets the drinking water standards as shown in Table 4.

The membrane filtration was operated very stably as shown in Fig. 3. The trans-membrane pressure corrected at 25 °C is shown in Fig. 3. The time interval of the membrane backwashing varied in the range between 30 and 60 min for both runs 3 and 4. The average daily increase of the corrected trans-membrane pressure is 1.7 kPa and 0.63 kPa for runs 3 and 4, respectively. Thus, the increase of the trans-membrane pressure is very moderate in run 4. The addition of NaClO solution to the backwash water was effective to prevent the membrane fouling and it is estimated that the chemical washing is required every 3 months when NaClO is added in the backwash process. The cycle of chemical washing will be shortened to 2 months without the addition of NaClO in the backwash process.

3.3. Chemical washing

Chemical washing was practiced to the ceramic membrane element exhausted in run 3. The element was washed with NaClO solution (0.3% as Cl_2) and rinsed with tap water. The element was subsequently washed with citric acid (1.0%) and rinsed with tap water. The specific filtration flux was measured with pure water before and after each step of chemical washing. The recovery of the membrane permeability is shown in Table 5. Most of the fouling substance was removed by NaClO and the remainder was cleaned out by citric acid. NaClO removed organic matter and aluminum while citric acid removed metals such as iron and manganese as well as aluminum as shown in Table 6. Thus the two step chemical washing resulted in a complete recovery of the pure water filtration flux.

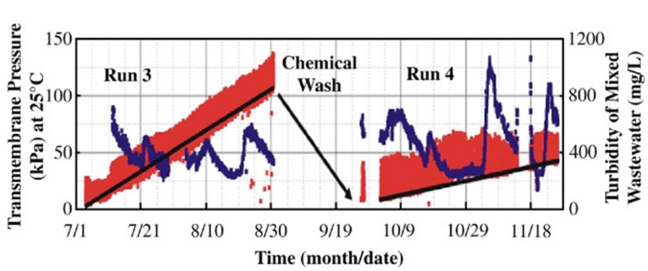

Fig. 3. Change of the corrected trans-membrane pressure.

Table 4
Quality of mixed wastewater and membrane filtrate.

		Influent to MF[a]			MF filtrate		
		Max	Min	Mean	Max	Min	Mean
Turbidity	TU	680	140	359	<0.1	<0.1	<0.1
Color	mg/L as Pt	4.9	1.5	2.3	1.9	1.2	1.4
$KMnO_4$ consumption	mg/L	292	109	190	5.5	3.3	3.9
Total Fe	mg/L	26.0	11.5	18.6	<0.01	<0.01	<0.01
Total Mn	mg/L	2.07	1.06	1.60	<0.005	<0.005	<0.005
Total Al	mg/L	72.5	62.6	68.0	0.06	0.02	0.03
Germs[b]	1/mL	–	–	–	Undetected		
E. coli	1/mL	–	–	–	Undetected		

[a] Influent: mixture of coagulation–sedimentation tank sludge and sand-filter backwash wastewater.
[b] Standard plate count.

Table 5
Recovery of pure water filtration flux by chemical washing.

	Specific filtration flux with pure water (m/d) at 100 kPa, 25 °C
Before run 3	28
After run 3	1.7
After washed by NaClO	22
After washed by citric acid	28
Before run 4	28

Table 6
Elution of metals and organics by chemical washing.

		Washing by NaClO	Washing by citric acid
Total Fe	mg/m^2	0.2	26
Total Mn	mg/m^2	0.04	21
Total Al	mg/m^2	73	120
TOC	mg/m^2	160	–

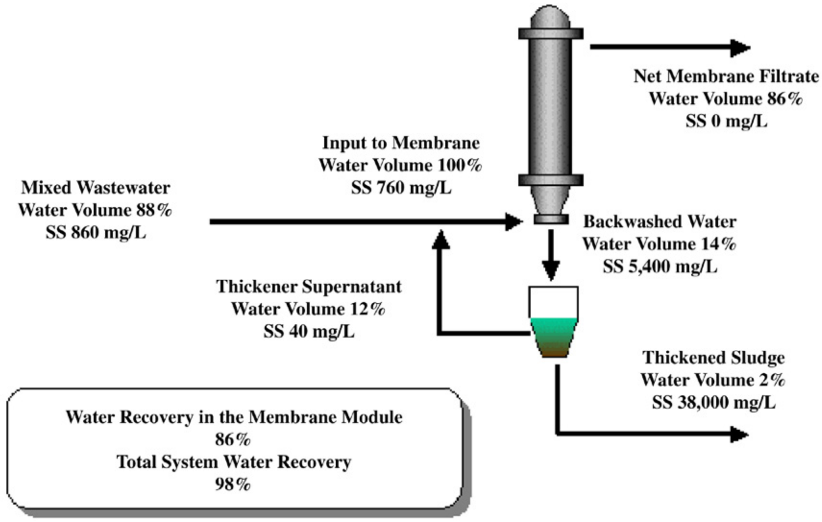

Fig. 4. Mass balance of water and suspended solids.

3.4. Water recovery

The mass balance of the membrane filtration process in runs 3 and 4 is shown in Fig. 4. About 14% of the filtrated volume was consumed for the backwash process and thereby the net recovery of the membrane filtrate is 86% on average. However, most of the membrane backwash wastewater was returned to the membrane filtration process and therefore the net recovery of the whole system is 98%.

4. Conclusions

The ceramic membrane filtration was operated very stably at the filtration flux of 4 m/day when the sand-filter backwash wastewater was fed. The membrane filtration was also operated very stably at the flux of 2 m/day when the mixture of the sand-filter backwash wastewater and the sediment sludge was fed. The concentration of suspended solids, turbidity, organics, and metals such as iron, manganese, and aluminum is very high in the feed water. However, the level of these substances in the membrane filtrate is very low and meets the drinking water standards. Chemical washing is required every 3 or 4 months for the treatment of the sand-filter backwash wastewater and is required every 2 or 3 months for the mixed wastewater to keep the trans-membrane pressure less than 100 kPa. Chemical washing with sodium hypochlorite and citric acid solutions effectively removed the membrane fouling substances. The net recovery of water volume in the whole membrane filtration process is 98%.

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